THE EBR-II STEAM GENERATING SYSTEM —
OPERATION, MAINTENANCE, AND INSPECTION

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ABSTRACT

The Experimental Breeder Reactor II (EBR-II) has operated for 20 years at the Idaho National Engineering Laboratory near Idaho Falls. EBR-II is a Liquid Metal Fast Breeder Reactor (LMFBR) with integrated power producing capability. EBR-II has operated at a capacity factor over 70% in the past few years. Superheated steam is produced by eight natural circulation evaporators, two superheaters, and a conventional steam drum. Steam throttle conditions are 438 C and 8.62 MPa. The designs of the evaporators and superheaters are essentially identical; both are counterflow units with low pressure nonradioactive sodium on the shell side.

During the 20 years of operation, components of the steam generator have been subjected to a variety of inspections including visual, dimensional, and ultrasonic. One superheater was removed from service because of anomalous performance and was replaced with an evaporator which was removed, examined, and converted into a superheater.

Overall operating experience of the system has been excellent and essentially trouble free. Inspections have not revealed any conditions that are performance or life limiting.

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THE EBR-II STEAM GENERATING SYSTEM — OPERATION, MAINTENANCE, AND INSPECTION

1. INTRODUCTION

Experimental Breeder Reactor II (EBR-II) has operated for 20 years at the Idaho National Engineering Laboratory near Idaho Falls, Idaho. EBR-II is a pool-type liquid metal fast breeder reactor (LMFBR) with integrated power plant. The steam-generating system uses heat from the reactor by way of the primary and secondary liquid-sodium systems. The steam generator consisted originally of eight natural-circulation evaporators, two once-through superheaters, and a single horizontal steam drum. The evaporators were arranged in two rows of four each and are connected to the steam drum by individual risers and downcomers. Steam separation takes place within the drum, and dry saturated steam is routed from the top of the drum through parallel-connected superheaters to a common header supplying the turbine. Feedwater is supplied to the drum, where it mixes with the saturated steam-water mixture before entering the downcomers. Table 1 lists the normal full-power operating parameters; Figure 1 is a schematic of the general layout of the system. Two evaporators and one superheater have been subjected to various types and amounts of inservice inspection. The superheater has subsequently been destructively examined.

Significantly, except for an initial construction tube-to-tubesheet weld defect, which resulted in a steam leak to the atmosphere, the steam generator has had a plant availability of 100%.

This paper describes the evaporators and superheaters and discusses the operation, maintenance, and inspections that have been performed during the first 20 years of operation.

2. DESCRIPTION OF EVAPORATORS AND SUPERHEATERS

The evaporators and superheaters are straight-tube heat exchangers with sodium flowing through the baffled shells. Except for the baffle-nest material of Type 304 stainless steel, all construction material is 2-1/4 Cr - 1 Mo ferritic steel. The only differences between the evaporators and superheaters are that core tubes are installed in the heat-transfer tubes of the superheaters to increase the steam velocity, and the superheaters are inverted in relation to the evaporators.

The units are designed to minimize the possibility of interaction between sodium and water/steam by using "duplex" tubes and double tubesheets (see Figures 2 and 3). Figure 2a shows an evaporator tube; Figure 2b is a superheater tube with an installed core tube. The sodium tubesheets are welded to the outer tubes to form the sodium cavity, and the steam tubesheets are welded to the inner tubes. No single weld, tube, or tubesheet separates the sodium from water/steam.

Two types of duplex tubing were used in the fabrication of the units. Four evaporators and one superheater contain mechanically bonded tubes, and the other units contain metallurgically bonded tubes. Fabrication of both types of tubes consisted of placing the outer tube over the inner tube and drawing the tubes together through a die and over a pin, leaving the tube undersized. This was followed by expanding the duplexed tube to its specified outside diameter by drawing a pin through the inside. In the case of the metallurgical tubes, prior to drawing the tubes, the outside of the inner tube was first coated (electroplated) with 0.13 mm of pure nickel and the inside surface of the outer tube with 0.013 mm of KANOGEN* nickel. Following the drawing operation, metallurgical bonding required a final operation of heating to flow the nickel-nickel phosphorous alloy between the tubes to produce a brazed tube-to-tube bond. The heating operation annealed out the radial prestress, which was introduced during the drawing operation. The mechanically bonded tubes were left in the stressed condition of outer tubes in tension and the

* Electroless nickel plating consisting of 11-13 wt % phosphorous in nickel.

inner tubes in compression. When installed, the evaporators and superheaters were designated as indicated in Table 2.

3. OPERATING HISTORY AND CHRONOLOGY OF EXAMINATIONS

Initial power of EBR-II was attained in July 1964. In the 20 years of operation, the steam generator has about 100 000 hours of steaming, and has experienced over 600 plant startups and about 370 reactor scrams. All-volatile (AVT) water treatment has been used since startup. Hydrazine (N_2H_4) is used to scavenge dissolved oxygen in the feedwater. Morpholine (C_4H_9NO) is used to maintain feedwater pH in the range of 8.6 to 9.2. Routine inspections of steam-drum internals, and surveillance of corrosion coupons located within the drum in both the steam and water space, have indicated minimal corrosion. Table 3 shows the normal feedwater quality during power operation.

On February 7, 1965, during a shutdown period with the steam system at ambient temperature, the operating crew reported that liquid water could be observed in the space between the steam and sodium tubesheets at the upper end of EV-702. The source of water was traced to a crater crack in one of the tube-to-tubesheet welds. Figure 4 is a photograph looking down through the outlet nozzle of the evaporator. Figure 5 is a closeup view of the defect after the surface was slightly ground. Liquid penetrant has been applied to assist in locating the precise leak site. The leak was obviously due to a birth defect that was not detected by the original helium leak test because it was at least partially plugged with slag. The defect was repaired by manual welding. Access was through the outlet nozzle shown in Figure 4. The steam riser from EV-702 to the steam drum had been removed for the repair. During the subsequent 20 years of operation, no additional leaks have been detected in any of the steam-generating equipment.

A chronology of steam-generator examination and pertinent operating and maintenance events is listed in Table 4.

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4. IN-SERVICE INSPECTIONS OF EV-702

Evaporator EV-702, which experienced a leak in 1965, has been subjected to periodic inspections of the steam side. In January 1969, the steam riser from EV-702 was removed and later reinstalled with mechanical flanges to permit reasonably easy access for examination. The first four inspections in January 1969, November 1970, April 1972, and April 1973 were all accomplished using either a borescope or TV camera. Although these examinations allowed for inspection of the repaired weld, the primary reason was to access the condition of the water side and monitor the effectiveness of the chemical treatment of the boiler feedwater.

4.1 Description of Visual Examinations

The riser walls, tubesheet, and a very limited portion of the evaporator tubes in EV-702 are visually examined as soon as practical after the unit is opened. A borescope has been used to look at the tube interiors before any cleaning is done, as well as after selected tubes are cleaned. Only a group of 19 tubes in the center of the tubesheet can be cleaned or inspected with rigid equipment.

Various cleaning techniques have been used to clean the 19 central tubes. These include dry brushing followed by water-wet swabs and acetone-wet swabs, dry brushing only, brushing with rotary and/or pump motion, and straight-through brushing. Only fiber (nylon) bristled brushes have been used.

The borescope image obtained in the upper portion of the tubes (approximately 4.6 m) is fairly good; however, as the distance between the viewing head and light increases from the eyepiece, the image becomes quite vague. The same problem is apparent with pictures taken through the borescope. Those taken near the top of the tubes (with a short borescope) are of much better quality than pictures taken through 7.3 or 9.1 m of borescope.

A TV camera, coupled with a videotape and TV screen, was used in the April 1973 inspection of the evaporator tubes. A flexible cable permitted the camera to be passed through the entire length of all 73 tubes.

4.2 Result of Visual Examinations

The surface of the metal in the system is covered with a deposit of brown magnetic (magnetite) material. Some of it is readily removed with a brush or cloth and some is rather firmly attached. The thickness ranges from zero to about 1-1/2 mm. No obvious pits or metal loss have been detected when the deposits were removed. Deeper accumulations of the loose material are found on top of the tubesheet.

No appreciable change has been detected in the metal surfaces of the steam tubesheet or tube interiors from one inspection to another.

After the evaporator tubes are brushed, both axial and circumferential fabrication marks can be seen through the borescope. Some spots or shallow pits have been observed which, by comparison with a prepared specimen, are estimated at less than 0.13 mm deep.

Relatively good images can be obtained, both for visual observation and photographs, when only two or three sections (3.7 to 5.5 m) of the borescope are used. As more sections of the instrument are used the image becomes quite indistinct. Also, the borescope becomes heavier and places more load on the connections, especially the one on the eyepiece section. Various means have been used to prevent the separation of borescope sections and also to keep a fallen section from passing through the tube should separation occur.

The TV camera provides a more convenient and safer method of inspecting the evaporator tubes (in the sense of losing things in the tube) . However, the results obtained are very poor, both for the instant TV presentation and the videotape presentation. Many features, tool marks, fabrication marks, spots, etc., that were plainly seen through the borescope could not be detected with the TV-camera system. The schedule has not permitted experimentation with the equipment to develop a satisfactory method.

Samples of the loose dark brown deposits that cover the top of the tubesheet were collected for chemical analysis. The powder is magnetic, and is believed to be primarily magnetite, Fe_3O_4. Analysis of two of the corrosion samples is presented in Table 5.

The general appearance of the tube surfaces examined was noteworthy. Generally, the first 0.6 m of the tubes appeared to have an evenly deposited thin film of oxide on the surface. The next 2-1/2 m had the general appearance of fine-grained sandpaper with some sparkle from the reflected borescope light. It is believed that the sandpaper appearance was the randomly distributed oxide flakes. This "sparkle zone" usually started approximately 0.6 m from the top and extended 1.8 to 2.4 m down. Attempts to obtain samples of the sparkle material were not successful. The material was thin, very hard, and tightly adherent.

4.3 Ultrasonic Examinations

1974 Examination

An initial in-service inspection of evaporator tubes from the inside (water side) was conducted to establish the feasibility of using ultrasonic shear waves as a nondestructive technique. A special transducer manipulator was designed so that the same transducer could be used to generate shear waves for defect detection and longitudinal waves for wall-thickness measurements. The experimental test arrangement was used to examine 19 tubes in evaporator EV-702 to a depth of ~4.3 m. In five of the inspected tubes, ultrasonic reflections from outside-surface abnormalities were obtained. The results, with regard to the position of these abnormalities, were reproducible; however, the amplitude variation during repeated tests exhibited a wide spread. Wall-thickness measurements were performed after the collimator was attached to the transducer. No wall thinning could be detected with visual observations of time-delay variations. Borescope examination of the evaporator tubes did not reveal any pitting or other surface phenomena.

The initial inspection demonstrated the feasibility of the examination method and pinpointed the weaknesses of the experimental procedure and equipment.

1976 Examination

Based on the experience from the 1974 exploratory manual ultransonic examination, a mechanized ultrasonic test system was developed and built to conduct inspection of the 2-1/4 Cr - 1 Mo steel duplex tubing in the EBR-II steam-generator system. Inspection required tube inspection from the bore side, complete volumetric examination, wall-thickness measurement, and evaluation of the braze condition. The test equipment was thoroughly checked and routinely calibrated, using a standard containing artificial flaws. Artificial flaws as small as 1.6 mm long by 0.25 mm deep were readily detected. The thickness-measurement results were more successful than expected. As anticipated, problems were experienced in penetrating poorly brazed regions. In areas of good bonding, the tube thickness was measured. In areas of poor bonding, the tube wall could not be measured because the beam would not penetrate the gap between the tubes. Sufficient bonding was present in the standards so that wall thinning could be determined. By use of the standard, changes of ±0.25 mm in thickness could be detected. The drive system and probe are shown in Figure 6. Figure 7 shows the inspection probe.

Of the 73 tubes in EV-702, 48 were examined. Some general observations could be made during scanning of the tubes. The hard scale on the inner surfaces of the tubes caused sound to reflect. The sound was picked up as noise by the ultrasonic instrument, and the recordings of the two inner-surface shear-wave gates exhibit a higher background noise than the outer-surface gate recordings. The top part of the tube was noisier than the bottom part. Brushing of the tube with soft nylon brushes did not remove the scale or eliminate the noise problem. During the examination it became obvious that the duplex bond quality was not uniform from tube to tube or even within a tube. Tubes with poor bond quality could not be examined past the braze because of high attenuation of the ultrasonic beam.

Two significant indications were identified on the outer surface of the tubes. The amplitude of the largest was equivalent to an electron discharge machining (EDM) notch 0.25 mm deep and 5 mm long. The second indication was classified as a small dent.

In summary, the mechanized equipment for ultrasonic inspection of evaporators provided a reasonably fast and repeatable inspection. After 12 years of operation, the results indicated a complete lack of any indications that would be detrimental to the integrity of the evaporator. The largest indication found would be reexamined in the future to determine any change in dimensions. The smaller indication was probably present in the initial fabrication of the tubes.

1978 Examination

The second ultrasonic inspection of the EBR-II steam-generator tubes was completed during March 1978. The first inspection, performed in 1976, provided baseline data to which the second inspection could be compared. The second inspection of the evaporator tubes was needed to (1) reexamine previously located ultrasonic indications to determine if these indications had changed and (2) inspect the tubes that were not inspected in 1976 to determine if they had defects. An addition to this second inspection was the use of a new probe to search for circumferential flaws.

Sixty of 73 tubes were inspected for longitudinal defects, and 11 of 73 were examined for circumferential defects. Six tubes had longitudinal indications of various lengths on the outside surface, with a maximum depth of 0.25 mm. Bore-side indications were found on 20 tubes. These indications were about 0.13 mm deep and 3 m long. All the indications have the characteristics of scratches or fabrication draw marks and have probably been present since fabrication. No circumferential flaws were found.

During the 1976 examination, only indications deeper than 0.25 mm were considered reportable. Five of the tubes with outer surface defects were also found in 1976 but four were not considered reportable. The fifth was the largest of the indications, and inspection was repeated in 1978. No change in dimension could be detected. The sixth defect was in a tube not examined in 1976.

5. ANOMALOUS PERFORMANCE OF SU-712

In 1974 the superheater containing mechanically bonded tubes began to show anomalous thermal behavior. The anomalous behavior was typified by a sudden decrease in outlet steam temperature occurring just as full power was approached. The magnitude of the decrease in outlet temperature varied from startup to startup and could not be correlated with any specific plant parameters. The magnitude of the decrease generally increased with time, and the power level at which the drop occurred appeared to be decreasing. This trend is shown in Figure 8, which shows the difference in steam outlet temperatures between the two superheaters as a function of calendar time. Measurements showed that individual tubes exhibited sudden drops in steam temperature and that the magnitude of the average outlet temperature was dependent on the number of individual tubes so performing. This behavior is explained by an increased thermal resistance of the duplex tubes caused by a reduction of the contact pressure, and in some cases, actual separation. Tube separation occurs when the differential thermal expansion between the inner and outer tube is sufficient to overcome the effect of residual tube prestress combined with steam system pressure within the inner tube. The increase in thermal resistance caused by reduced contact pressure or tube separation results in a larger temperature difference between the two tubes, which leads to further separation. This process continues, along with a decrease in the superheater power level, until stable heat transfer conditions exist.

No plausible mechanism other than an increase in thermal resistance of the duplex tubing caused by a decrease in the contact pressure, or possibly actual separation between the inner and outer tubes, has been proposed.

6. IN-SERVICE INSPECTION OF SU-712

The anomalous behavior of SU-712 discussed above prompted the 1979 inspection of SU-712 to determine the potential for continued degradation and failure. The steam side of the superheater was examined by visual, dimensional, ultrasonic, and weld-inspection methods. Three core tubes were removed to provide access to the inside of the heat transfer tubes for examination. The core tubes were replaced with new ones, leaving the originals available for destructive examination. To gain access for the examinations, the steam piping was cut at the inlet and outlet reducers and moved aside. This provided straight direct viewing of the central seven tubes. Figure 9 shows a view of the tubesheet in the inlet steam chest.

6.1 Steam Chests

Visual examinations of the inlet and oulet steam chest did not reveal any unusual conditions. Horizontal surfaces were covered with a dark rust-red thin film of magnetite (Fe_3O_4). Vertical surfaces were covered with a thin layer that presented a silvery, crystalline effect.

6.2 Core Tubes

Core-tube ends were intact and uniform, except for one core tube that had a small hole at each end at the base of the crimp, and one that was elevated by about 13 mm above the prevalent elevation of the rest of the core tubes. Most of the crimped ends had indentations at the bearing points against the ends of the steam tubes. Some core tubes were loose and could be rotated and slightly displaced axially. Others resisted any manual displacement. All were movable after slight tapping of the bottom ends. The three removed core tubes had slightly mottled outside surfaces, with lightly scattered gray blisters and black spots. The gray blisters were easily removed, leaving black spotting underneath. Diameters across the tube bosses measured about 0.5-0.9 mm less than the steam-tube inside diameters.

Two of the three removed core tubes were destructively examined. Chemical analyses showed no service-induced changes. Tensile tests revealed some ductility loss and revealed a gradual decrease in maximum test load from the cold end toward the hot end. Sectioning of bossed areas showed only minor amounts of wear. The tube surfaces were found to be mainly protected by a heavy, brittle layer of magnetite, but occasional pitting was found. Microstructural analyses of the outside surfaces revealed a thin decarburized zone. Hardness in the decarburized zone was slighlty reduced from that of the base material.

6.3 Steam Tubes

The ends of the steam tubes had very slight dents where the core tubes bore against them. The degree of denting ranged from discoloration only to an estimated 0.5 mm. The insides of the tubes had lightly scattered spots of light-gray scale, underneath which was evidence of slight pitting. There was also lightly scattered dark spotting, which appeared to be slight corrosion and pitting. There were marks where the core-tube bosses touched the steam tubes, and dark corrosion product appeared to have built up slightly around these spots.

Ultrasonic inspection of the three selected steam tubes revealed one indication on the outer surface of a sodium (outer) tube about 0.38 mm deep and 9.7 mm long. An evaluation of the quality of the bond between duplex tubes was attempted using ultrasonic inspection. The results lead to some speculation that the bond may be better at the steam-inlet end.

The inside diameters of the three tubes measured about 0.05 mm smaller than specified in the drawings.

6.4 Tube-to-tubesheet Welds

Visual examination of all the weld surfaces revealed no apparent service-induced cracking. Liquid-penetrant inspection of the welds at both ends of three tubes revealed no cracking, but indicated minor weld-crater pits at four locations. No indications appeared in the bores of the tubes, which were inspected to a depth of 13 mm.

6.5 Steam-tube Straightness

The maximum displacement from centerline found in the three tubes measured was about 8.4 mm. The location of maximum deviation was slightly below the center in all three tubes, approximately 60% of the distance from top to bottom.

6.6 Summary of SU-712 Examination

The overall assessment of the examination results is that the unit was surprisingly clean and appeared to be "like new." There were no unusual conditions or any unusual wear. It is important to point out that only steam-side examinations were conducted.

A surprising and significant result of the examination was that it was possible to conduct a meaningful ultrasonic examination of the mechanically bonded duplex tubing.

7.0 EXAMINATION AND CONVERSION OF EV-706

Because of the continued anomalous performance of SU-712, and because it was desirable to make the unit available for destructive examination, a plan was prepared to remove SU-712 from service. Calculations and measurements confirmed that an evaporator could be removed with negligible effect on the overall performance of the steam-generating system. It was decided to remove EV-706 from service in April 1980. The unit would be inspected and converted to a superheater. In 1981, the following year, the converted EV-706 would replace SU-712. EV-706 was selected primarily because it contained metallurgically bonded duplex tubes.

After removal, EV-706 was subjected to the following operations and examinations:

(1) Chemical and mechanical cleaning
(2) Tube borescope examinations
(3) Tube inside-diameter measurements
(4) Liquid penetrant examination of tube-to-tubesheet welds
(5) Tube ultrasonic inspections

7.1 Chemical Cleaning

A low-temperature mild acid cleaning process was employed. Though other methods were known to more effectively remove deposits, it was important to avoid removing base metal. Therefore, the process used was a citric acid process at 82°C with a protective agent, Rodine 31A, to protect bare metal surfaces from acid attack.

The process was stopped when additional scale reduction ceased as indicated by solution samples.

7.2 Ultrasonic Inspection of EV-706 Duplex Tubes

All of the 73 tubes were examined longitudinally. Examination of the duplex tubing was conducted with specially designed mechanized equipment and ultrasonic probes. Five tubes had indications on the outside surface. Eleven tubes had inside-surface indications which were identified as draw marks with no real significant size. The draw marks were verified visually after the ultrasonic scanning was completed.

Within the limits of repeatability of the mechanized inspection device, there was no reason to believe that any inside or outside indications found would be detrimental to the integrity of steam generator EV-706. All indications, inside as well as outside, are believed to have been in the tubes since the original fabrication.

The unit was found to be acceptable in all respects for reinstallation into the system as a superheater. The only observation of note was the discovery of substantial deposits in most of the tubes about 2 m from the top. The deposits were of the order of 0.13-0.25 mm thick and extended over a tube length of less than 250 mm long. The deposit was not removed by the chemical cleaning. Attempts to remove it by a mechanical process called "hydroblasting" was only partially successful. Sufficient material was removed to obtain a sample for chemical analysis. The results are listed in Table 6.

It was judged that these deposits would not be detrimental to the performance of the unit when installed as a superheater. No further attempt was made to remove them. Conversion of EV-706 was completed by inverting it and installing core tubes.

8. REPLACEMENT AND EXAMINATION OF SU-712

During the scheduled annual maintenance shutdown in the spring of 1981, superheater SU-712 was removed and the converted evaporator EV-706 was installed in its place. Operation of the steam-generating system has been normal in all respects since the removal of SU-712. The plant is now operating with seven evaporators instead of the original eight. The performance of the converted EV-706 as a superheater has been slightly better than that of the original SU-710.

Final results of the destructive examination of SU-712 are not available for publication at this date. Results do, however, confirm the original hypothesis explaining the anomalous performance; that is, the anomalous behavior is partly explained by an increase in thermal resistance of the duplex tubes caused by a reduction in the contact pressure.

9. SUMMARY

Twenty years of near trouble-free operation of the EBR-II steam generating equipment have demonstrated the adequacy of the design, construction, and operating conditions. Inservice inspections of the equipment have not revealed any basic problems inherent in the design or operating conditions that are limiting to the life of the equipment.

The results obtained by operating EBR-II with the all-volatile water chemistry confirms the adequacy of this treatment. It is important to note that no difficulties have been encountered in maintaining high feedwater quality without full-flow demineralization. This has been accomplished in a system with ferritic steel steam generators, a main condenser wtih admiralty brass tubes, and less than 10% continuous steam drum blowdown.

Ultrasonic examination of both metallurgically and mechanically bonded duplex tubing has been reasonably successful. Scale deposits on the water side of the tubes were the biggest impairment to the ultrasonic technique. Sound-wave reflection and scattering caused by the microcrystalline structure of the scale deposits was responsible for a high noise/signal ratio in general. This condition could probably have been much improved if the scale were first removed. However, only mild cleaning techniques were attempted. For conservative reasons, it was deemed prudent not to use harsh cleaning methods that would remove the protective coating. More development work would be useful in improving cleaning and conditioning methods prior to and after ultrasonic examination.

The anomalous behavior of the superheater with mechanically bonded duplex tubing is providing valuable information about stress relaxation properties of 2-1/4 Cr - 1 Mo material. While this anomalous behavior has not caused any operational problems at EBR-II, the information being provided is very important with regard to future designs using this material and duplex tubes. The superheater has been made available for examination by converting one of the existing evaporators to a superheater and replacing the original superheater with the converted unit. This was possible without having any impact on the plant's operation because of excess capacity available in the present evaporators.

The life expectancy of the steam generators is not clearly defined, but there are not apparent limitations after 20 years of operation. Many more years of troublefree operation appear likely.

10. ACKNOWLEDGEMENTS

This work was performed under the auspices of the United States Department of Energy.

TABLE 1

EBR-II STEAM GENERATOR OPERATING PARAMETERS

Power	62.5 MWt
Feedwater Temp.	288 C
Steam Drum Pressure	9.14 MPa
	1325 Psi
Superheated Steam Temperature	438 C
Blowdown	2.5 kg/s
Steam Flow	30.9 kg/s
Circulation Ratio	10

TABLE 2

IDENTIFICATION ASSIGNED TO EVAPORATORS AND SUPERHEATERS

Metallurgically Bonded Evaporators (South Bank)	Mechanically Bonded Evaporators (North Bank)
EV-702	EV-701
EV-704	EV-703
EV-706	EV-705
EV-708	EV-707

SU-710	Metallurgically Bonded Superheater
SU-712	Mechanically Bonded Superheater

TABLE 3

FEEDWATER QUALITY DURING POWER OPERATION

	EBR-II*
Total Dissolved Solids	~0
Dissolved Oxygen	< 5 ppb
Silica	< 10 ppb
Iron	< 10 ppb
Copper	< 20 ppb
pH	8.6 - 9.2
Hydrazine (Residual)	10 - 20 ppb
Sodium	< 0.1 ppb
Chlorides	< 20 ppb

*Concentrations shown as < are lower than measurement capability.

TABLE 4

STEAM GENERATOR INSPECTIONS AND PERTINENT OPERATING AND MAINTENANCE EVENTS

Event	Date
Initiate Power Operation	July 1964
Steam Leak and Repair of EV-702	Feb. 1965
Visual Inspection of EV-702	Jan. 1969
Visual Inspection of EV-702	Nov. 1970
Visual Inspection of EV-702	April 1972
Visual Inspection of EV-702	April 1973
Visual and Ultrasonic Inspection of EV-702	April 1974
Visual and Ultrasonic Inspection of EV-702	March 1974
Visual and Ultrasonic Inspection of EV-702	March 1978
Anomalous Behavior of SU-712 Noted	Jan. 1978
Inservice Inspection of SU-712	April 1979
Removal, Examination and Conversion of EV-706	April 1980
Replacement of SU-712	April 1981
Perform Destructive Examination	In Process

TABLE 5

EVAPORATOR EV-702 CORROSION PRODUCTS ANALYSIS

Element	1974 Content	1976 Content
Fe	10.5%	39.7%
Cr	0.6%	0.45%
Ni	4.8%	8.4%
Cu	29.2%	24.0%
Mn	0.3%	0.29%
Sn	<1250 ppm	0.9%
Mo	< 240 ppm	196 ppm
Ca	0.9%	172 ppm
Si	ND*	687 ppm
SiO_2	ND*	1468 ppm

* Not Determined

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TABLE 6

CHEMICAL ANALYSIS OF TUBE DEPOSITS
REMOVED FROM EV-706
BY HYDROBLASTING

Element	Wt %
Al	0.007
Ca	0.4
Co	0.02
Cr	0.2
Cu	15.0
Fe	4.0
Mg	0.07
Mn	0.02
Mo	0.002
Ni	3.2
Pb	0.01
Si	0.01
Sn	0.03
Ti	0.007

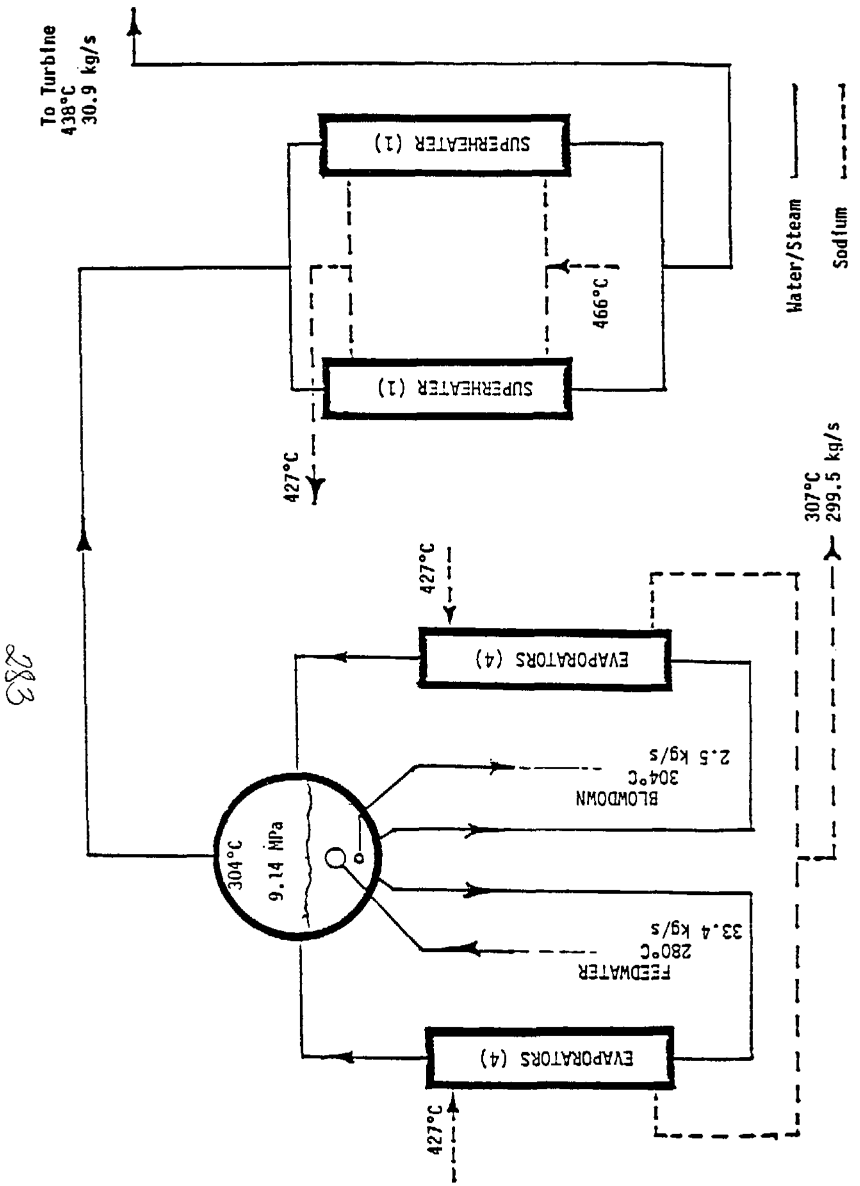


Figure 1
EBR-II STEAM GENERATING SYSTEM

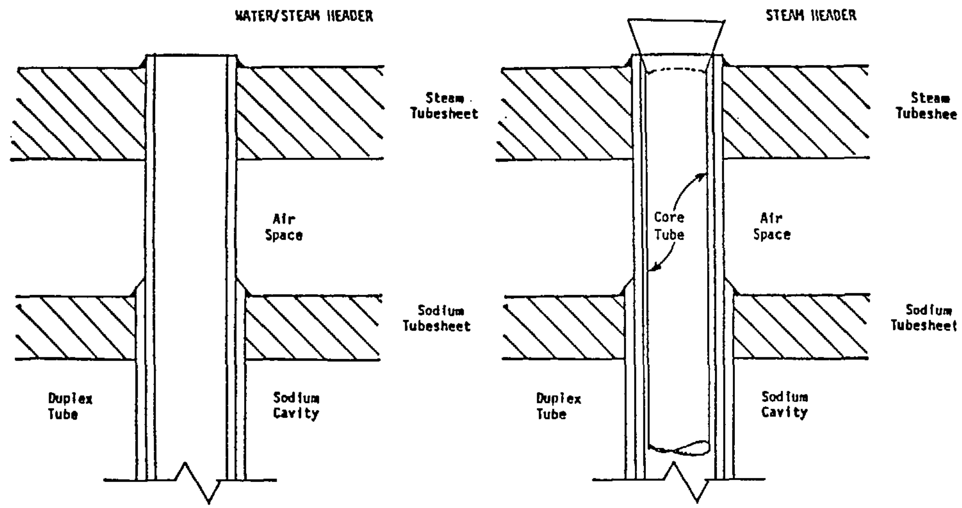


Fig. 2a Evaporator Tube   Fig. 2b Superheater Tube

TUBE DIAMETERS

Inner Tube	Outer Tube	Core Tube
I.D. - 27.05 mm	I.D. - 31.75 mm	I.D. - 19.22 mm
O.D. - 31.75 mm	O.D. - 36.53 mm	O.D. - 20.64 mm

Figure 2

DUPLEX TUBE - DOUBLE TUBESHEET ARRANGEMENT

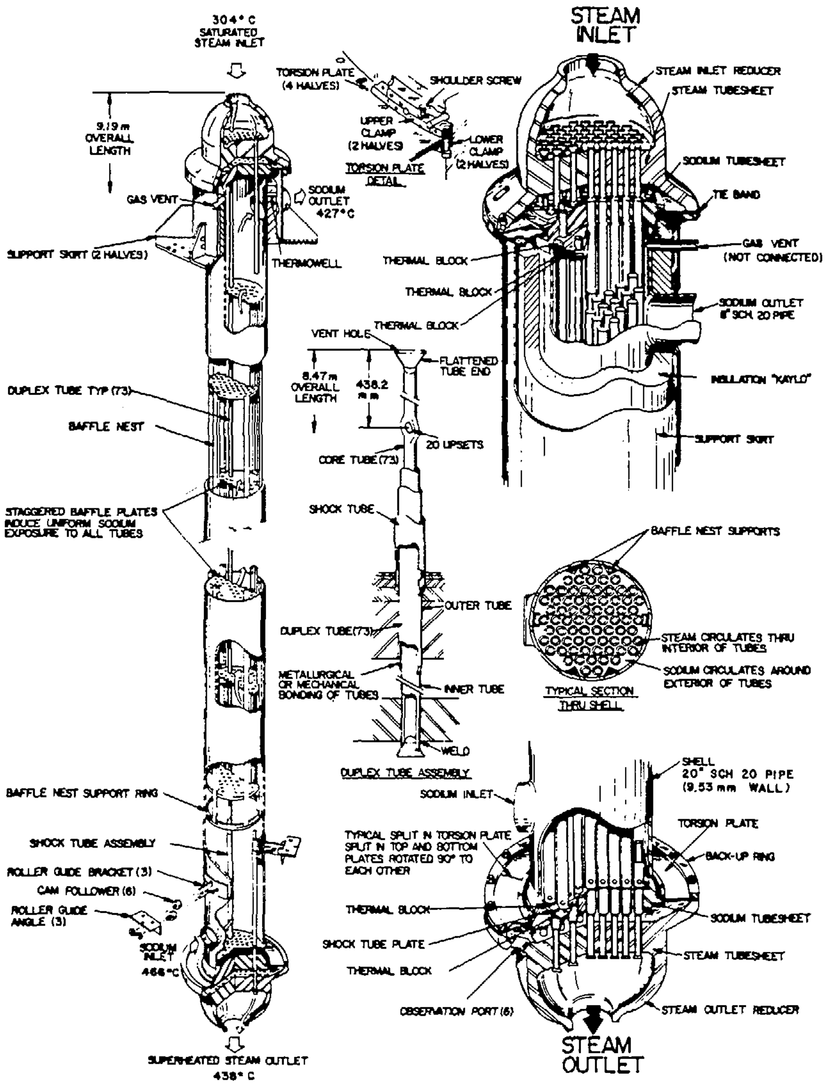


Figure 3

SUPERHEATER ASSEMBLY

1-25

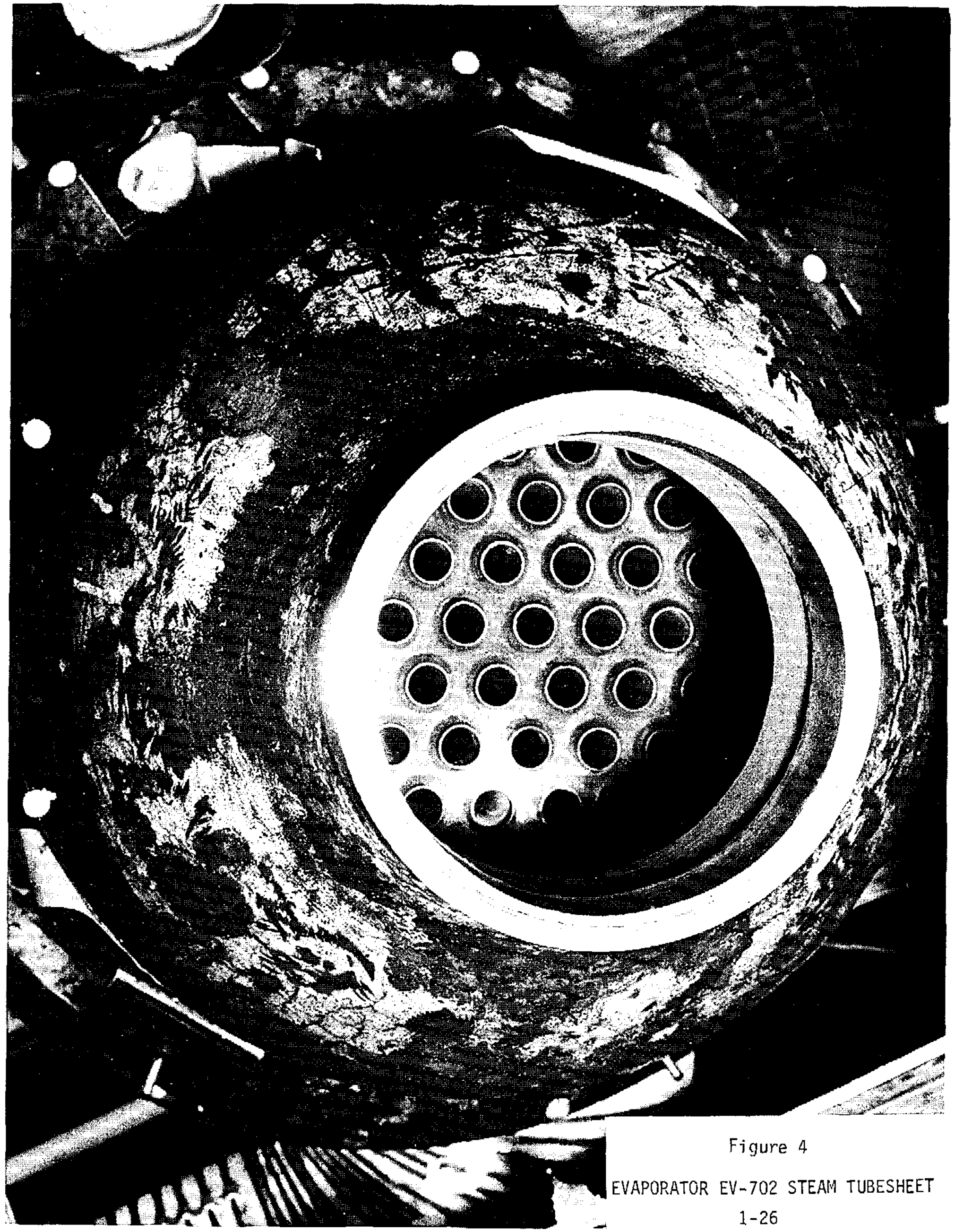


Figure 4

EVAPORATOR EV-702 STEAM TUBESHEET

1-26

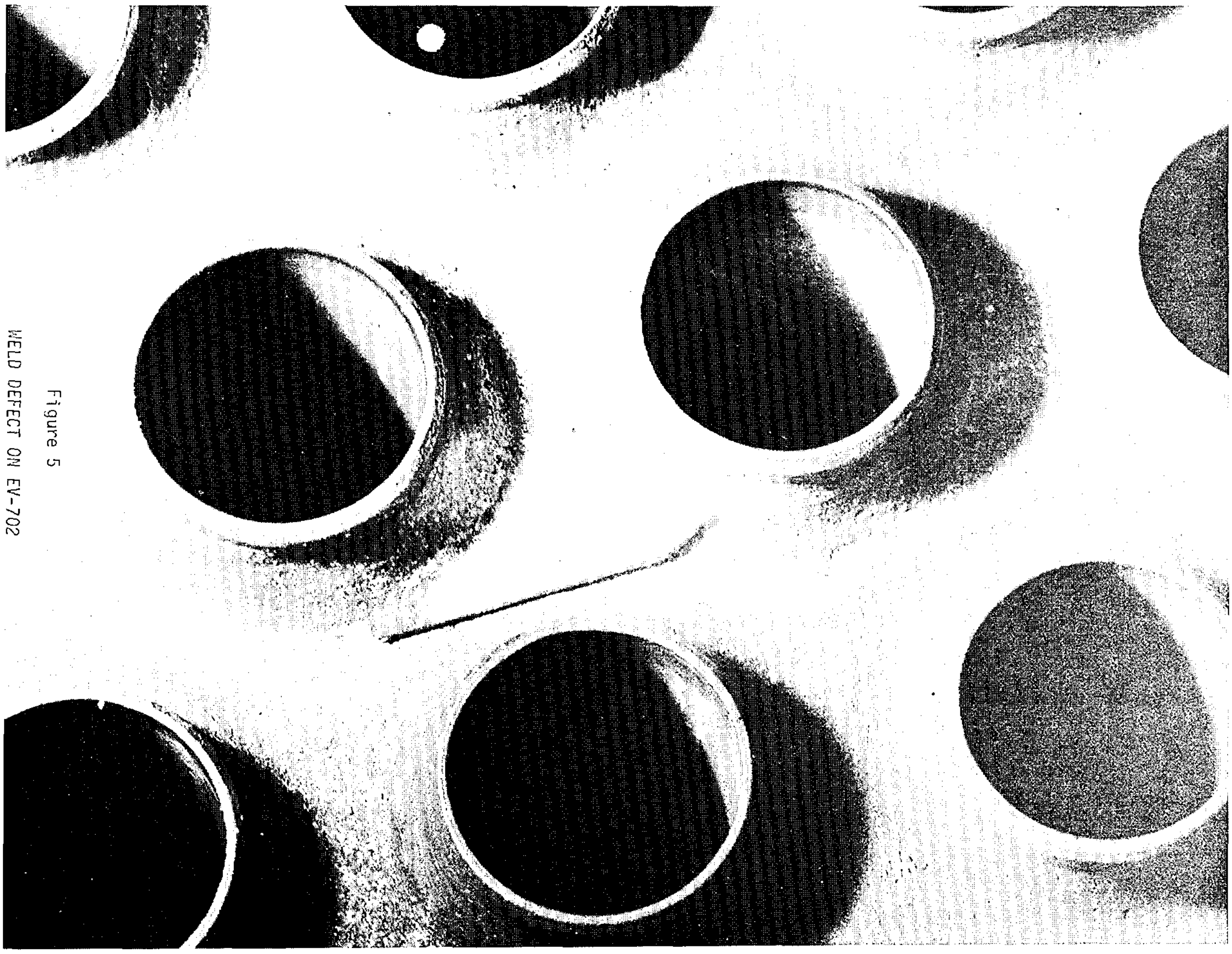


Figure 5

WELD DEFECT ON EV-702

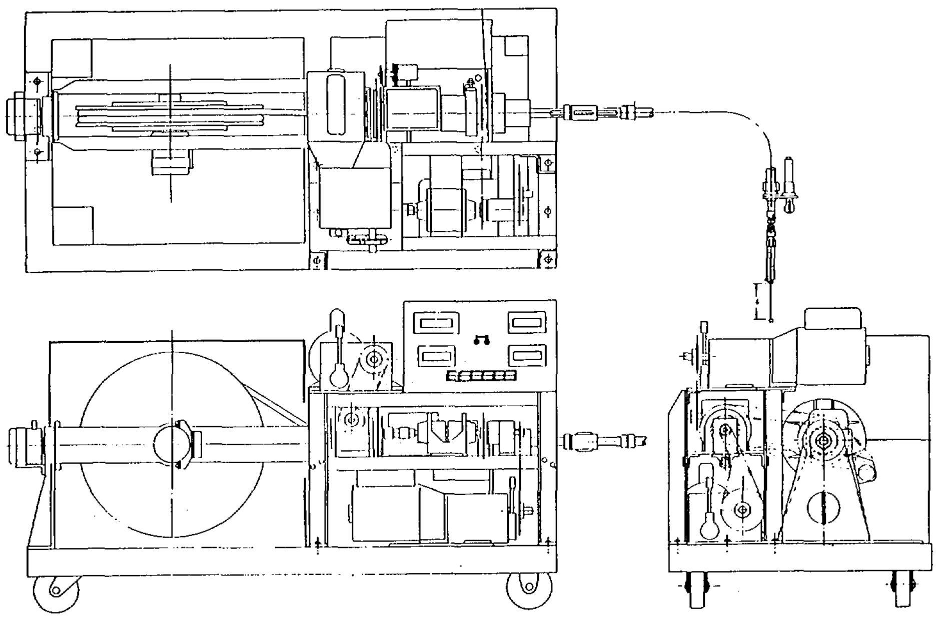


Figure 6

SCHEMATIC OF ULTRASONIC MECHANICAL DRIVE SYSTEM

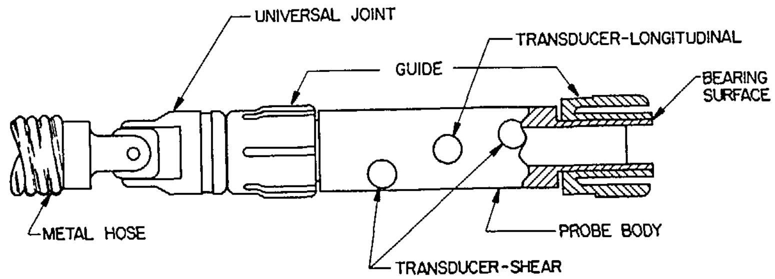
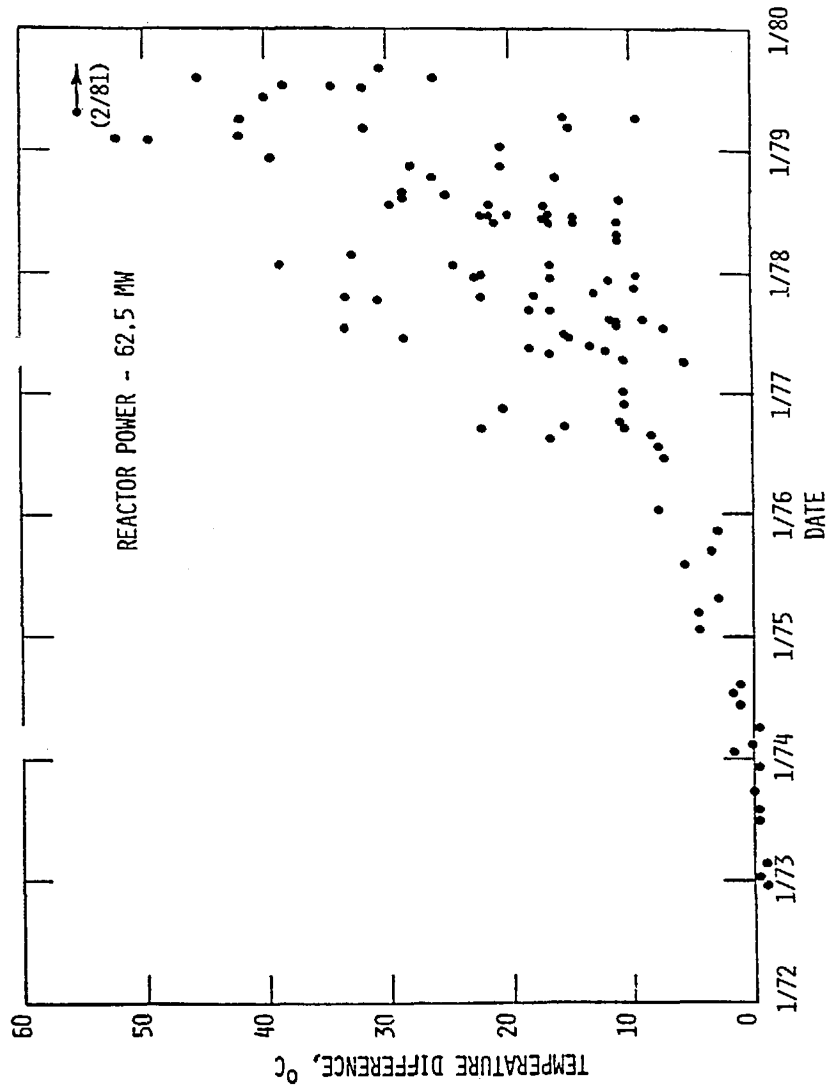


Figure 7

ULTRASONIC INSPECTION PROBE



SUPERHEATER STEAM OUTLET TEMPERATURE DIFFERENCE

Figure 8

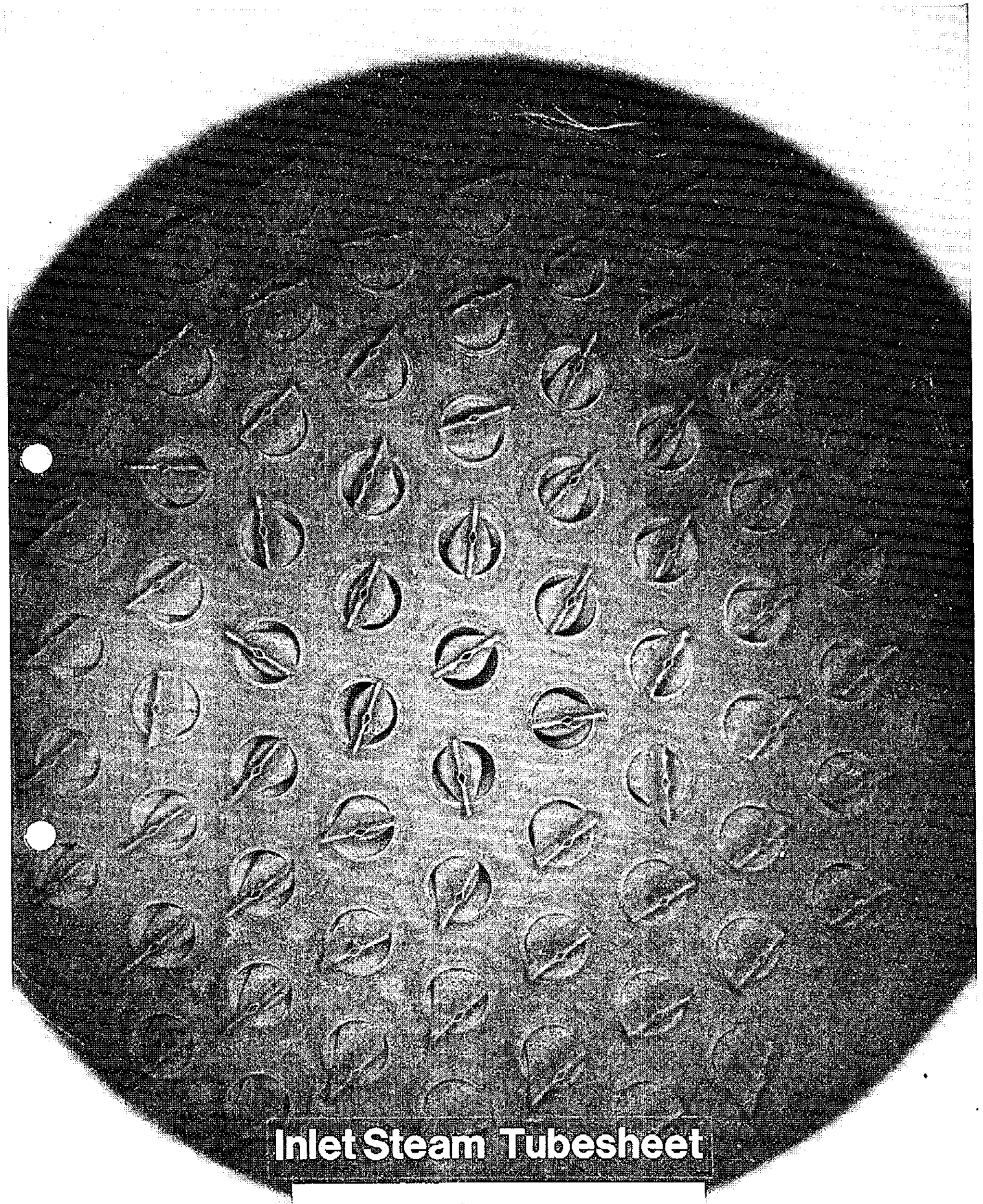


Figure 9

SUPERHEATER SU-712 INLET STEAM TUBESHEET

Question and Answer

Session 3 & 4 Paper No.17

Paper Title : The EBR-II Steam Generating System Operation, Maintenance and Inspection

1. Minguet

Q. You have found possible defect indication with US examination of your double walled tube. Were they cracks ? What were their dimensions ?

A. The indication corresponding to the photograph was a scratch about 0.25mm deep and 5Dmm long. The UT indication was equivalent to an EDM notch about 0.38mm deep and 9.7mm long. No indications were found due to cracks. Most indications were found to be original draw marks. These draw marks were less than 0.13mm deep. Some where as long as 3m.

2. Salgo

Q. Can you give me some data on the deformation twisting of the tube bundle you saw during the visual inspection of the SH bundle ?

A. About 1 tube diameter (3.5cm) at outer row of tubes.

3. Salgo

Q. Did the SG suffer from severe accident transients during the plant life (for instance fast sodium pump stop, etc.)?

A. I believe the most severe transient is following a reactor scram. The sodium inlet temperature will drop from 883°F to 700°F very rapidly. However, there is no problem.

4. Westenbrugge

Q. You have no flow shroud.

A. There is no flow shroud. There are baffles spaced at around 1m apart.

5. Westenbrugge

Q. You use no means of compensation for differential expansion.

A. No special means is provided; however the tubes are prestressed in compression when cold.

6. Westenbrugge

Q. What inspection did you perform on tube-tube sheet welds ?

A. Radiographic, but not all welds, liquid penetrant, and helium test.

7. Westenbrugge

Q. Did you find complete SH bundle bowed ?

A. The tube bundle along with baffle most loose twist. Approximately 1 tube diameter at outer row of tubes.

8. Westenbrugge

Q. Did you observe any bowing in EV ?

A No significant bowing was observed in EV. Some bowing is present, but it has not been measured.

9. Westenbrugge

Q. Cause?

A. We believe it to be a result of the fabrication procedure.

10. Westenbrugge

Q. What is the heat conductance of the joint of the two concentric tubes ?

A. Contact resistance before reduction of performance is about $2.6 \times 10^{-5}\ \frac{m^2K}{W}$, after performance has degraded my recollection is an increase in resistance of a factor of 10-20.

11. Avanzini

Q. What is the reason why you have used merallugical bonded duplex tubes ? I think that mechanical bonded tubes will be have better with regard to the inhibitation of crack propagation at the interface between the two layers.

A. It is the other way around. Metallugical tubes were first specified and used. Because of cost remaining tubes were bonded mechanically. Tests and calculations have verified that crack will stop at the interface for either type of tube.

12. Minguet

Q. Are the baffles free to rotate ?

A. The baffles are tied together with tie bars. This assembly is welded to the shell nearest the steam inlet. The baffle assembly must twist with the tubes.

13. Minguet

Q. What are the exact dimensions of tubes?

A. Tube dimensions are in the paper Fig.2.

14. Minguet

Q. Is the twisting of the bundle a cause for loss of heat transfer performance ?

A. Twisting is not a cause for loss of performance.

15. Minguet

Q. Do you have possibility of ISI of tube-tube sheet welds ? Have you forseen repair procedure ?

A. No.

16. Tanabe

Q. Tell me the number of tubes which showed such abnormal behavior. What about tubes of other SH ?

A. Up to about 3/4 of the total 73 tubes, but not always the same tubes. Because those of the other superheater were metallugically bonded, such behavior was not shown. It was not observed to occur in EV's either.

17. Anderson

Q. What was the chemical cleaning protective agent, Rodine 31A ?

A. Don't know.

18. Anderson

Q. What sort of destructive examination has been done on SU-712 ? Is it strictly associated with the duplex tube issue or have you taken advantage of the availability of this unit to do other examinations ? If so, what ?

A. It has been subjected to a wide variety of inspections and test, both mechanical and metallugical. Availability has been taken advantage to conduct just about all the examination imaginable. Result will be published.

19. Anderson

Q. Is it possible that the duplex tube separation is associated with off center positioning of core tubes ?

A. No.

20. Hayden

Q. Could you comment on the 250mm long 0.25mm thick deposit. Is it the result of carry over ?

A. This deposit was found in evaporator EV-706. There is no carry over . It is all water that enters the evaporaor. The temperature is slightly below saturation. The deposits occur as the steam void fraction is becoming large and probably this causes the deposision. The heat flux in this area may also be a contributing factor.